United States Department of Agriculture

NRCS

Natural Resources Conservation Service
National Soil Survey Center
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Phone: (402) 437-5499
FAX: (402) 437-5336

SUBJECT: MGT – Geophysical Assistance

March 19, 2010

TO: Phoukham Vongkhamdy
State Conservationist, NRCS
Warwick, Rhode Island

File Code: 330-7

Purpose:
The focus of this study was to improve our understanding of the variations and distributions of freshwater subaqueous soil types. An objective was to develop improved GPR field methods and interpretive procedures for identifying, classifying, and mapping subaqueous soils and landscapes. Also, an area that had been mapped as predominantly Poquonock soils on Conanicut Island was traversed with GPR. The soil staff in Rhode Island is updating its soils maps and desires to know if mapped areas of the very deep to bedrock Poquonock soils have inclusions of shallower soils.

Participants:
Jonathan Bakken, Graduate Student, University of Rhode Island, Kingston, RI
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Maggie Payne, Soil Scientist, USDA-NRCS, Warwick, RI
Donald Parizek, Soil Scientist, USDA-NRCS, Tolland, CT
Debbie Surabian, Soil Scientist, USDA-NRCS, Tolland, CT
Jim Turenne, State Soil Scientist, USDA-NRCS, Warwick, RI

Activities:
All field activities were completed on 8 thru 10 February 2010. Heavy snows and adverse field conditions on 10 February caused the suspension of field work.

Summary:

1. Ground-penetrating radar surveys were completed on ice over three bodies of water in Rhode Island: Bowdish Reservoir, Smith and Sayles Reservoir, and Tucker Pond. These GPR bathymetric surveys revealed relatively shallow waters within Bowdish Reservoir (average water depth is 1.42 m with an observed range of 0 to 2.61 m) and Smith and Sayles Reservoir (average water depth is 1.77 m with an observed range of 0 to 2.76 m). These reservoirs have extensive areas with water depths within the limits for subaqueous soils. Both of these reservoirs have extensive areas of submerged organic soil materials that are thick enough to be classified as Frasiwassists (taxonomic great group). Tucker pond has greater water depths (average water depth was 4.54 m with an observed range of 0 to 7.68 m) and extensive areas that are outside the proposed depth range (<2.5 m) for subaqueous soils. The subbottom materials are largely mineral, and consequently, shallower areas would be mapped as Frasiwassents.

2. The subaqueous soil environments that were surveyed are exceedingly complex in terms of soil materials, topography and formative processes. This variability can be great over surprisingly short distances as testified in the examples provided in this report.

3. In order to accurately interpret different radar reflection patterns and signal amplitudes, subaqueous soils should be cored for identification where subsurface patterns change. Unfortunately, this procedure was not adequately accomplished during this survey. As a consequence, not all subbottom materials could be accurately identified. Timely and well-positioned cores will greatly improve GPR interpretations and should be carried out in all future GPR surveys of freshwater subaqueous soils.

4. Two GPR traverses were conducted in an area of very deep Birchwood and Poquonock soils. These traverses confirmed the suspicion of Jim Turenne that ledge occurs at shallower depths within these units and interpretations are incorrect. Based on over 34, 800 picks on two radar records, soils were found to be dominantly deep (53%) and moderately deep (36 %). Only 11 % of the soils, however, are very deep, the depth class presently identified with the soil map units.

5. All radar records have been turned over to Jim Turenne for further analysis and interpretations.

/s/ Craig Ditzler, Acting

JONATHAN W. HEMPEL
Director
National Soil Survey Center

Enclosure

cc:
James A. Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Micheal L. Golden, Director, Soil Survey Division, NRCS, Washington, DC
David Hvizdak, State Soil Scientist/MO Leader, NRCS, Amherst, MA
Kipen J. Kolesinskas, State Soil Scientist, NRCS, Tolland, CT
Jim Turenne, State Soil Scientist, NRCS, Warwick, RI
John W. Tuttle, Soil Scientist, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Larry T. West, National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
Michael A. Wilson, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE

Technical Report on Ground-Penetrating Radar Investigations conducted over Subaqueous Soils in Rhode Island on 8 to 10 February 2010.

Jim Doolittle

Background:

> "The concept that sediments in shallow water environments undergo soil forming processes, are capable of supporting rooted plants, and meet the definition of soil according to the criteria defined in Soil Taxonomy has been moving soil scientists into a new frontier of soil survey – mapping subaqueous soils."
> (Jim Turenne; http://nesoil.com/sas/sasinfo.htm).

Subaqueous and submerged soils occur under both fresh and salt waters. These soils have the ability to support rooted plants in natural environments. The lower water depth limit for subaqueous soils is presently proposed at the arbitrary depth limit of 2.5 meters. This depth limit has been proposed because it is assumed to represent the "*normal*" maximum depth to which most emergent vegetation will grow. However, in some areas, emergent vegetation is known to grow at deeper depths.

In order to document, map, and classify subaqueous soils, it is important to have knowledge of water depths, bottom topography, sediment types and thickness. Over open water, acoustical (fathometers, acoustic sub-bottom profilers (SBP)) and radio frequency ground-penetrating radar (GPR) have proven to be effective in providing information on water depths, bottom topography, sediment types and thickness (Feurer et al., 2008). However, these open-water "*remote sensing*" methods, because of drift, often suffer from imprecise positioning of verification and sampling core sites (Moorman and Michael, 1997). Ground-penetrating radar, however, can be used on ice-covered water bodies, which provides more accurate positioning of core sites.

Ground-penetrating radar has been used extensively for bathymetric surveys of fresh water lakes (Fischer et al., 2007; O'Driscoll et al., 2006; Buynevich and Fitzgerald, 2003; Moorman, 2001; Moorman and Michel, 1997; Mellett, 1995; Sellmann et al., 1992; Izbicki and Parker, 1991; Truman et al., 1991; Haeni et al., 1987) and rivers (Sambuelli et al., 2009; Feurer et al., 2008; Spicer et al., 1997; Kovacs, 1991; Annan and Davis, 1977). In these studies, GPR provided continuous, detailed two-dimensional records of the subbottom sediment type, thickness, and topography. These studies illustrate how GPR records provide more detailed observations into subbottom conditions than possible from core data alone. Traditional coring methods are labor intensive, and have very high cost/area ratios (Feurer et al., 2008). As a consequence of the costs and limited numbers of cores, this method often suffers from an oversimplification of relatively complex subaqueous environments (Stevens et al, 2009). Ground-penetrating radar can provide more complete and continuous records, which document spatial changes in subaqueous soils. Accurate radar interpretation, however, requires a lesser, but still adequate number of available core data to confirm interpretations.

In reported studies conducted in low-conductivity waters, GPR has been used to identify the water / bottom-sediment interface to depths as great as 22 to 25 m (Delaney et al. 1992; Sellmann et al., 1992), and provide accurate and detailed bathymetric cross-sections and contour maps. Moorman and Michel (1997) reported GPR measurements of fresh-water lake bottoms to depths as great as 19 m with an accuracy of ± 3%. However, in more conductive waters, GPR is more depth restrict. The use of GPR in brackish or salt waters is impractical because of their high electrical conductivity and attenuation rates, which severely restricts penetration.

The purpose of this investigation was to obtain data on water depths, subbottom topographies and sediment types within natural and impounded bodies of fresh water in Rhode Island.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (*GSSI*; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate (see Fig. 1). Jol (2009) and Daniels (2004) provide discussions on the use and operation of GPR. An antenna with a center frequency of 70 MHz was used in this study.

Figure 1. Debbie Surabian operates the SIR-3000 system with AG114 GPS receiver as Jim Doolittle caries the 70 MHz antenna across Bowdish Reservoir.

The RADAN for Windows (version 6.6) software program (*GSSI*) was used to process the radar records shown in this report.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (see Jol (2009) and Daniels (2004) for discussions of these techniques).

Recent technical developments allow the integration of GPR with GPS. The SIR-3000 system provides a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). Following data collection, a subprogram within RADAN for Windows software is used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver. A Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to collect position data. With this setup, position data are recorded at a time interval of one second along GPR traverse lines.[1]

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[1] Trade names are used for specific references and do not constitute endorsement.

Using the *Interactive 3D Module* of the RADAN for Windows software program, depths to water/subbottom interface were automatically and reasonably accurately picked, and outputted to a worksheet (X, Y, Z format; including latitude, longitude, depths to interface or layer, and other useful data). Using this module, data were compiled and exported for future plotting and visualization in GIS.

Field Methods:
For the bathymetric surveys, GPR traverses were completed with the SIR-3000 system and a 70 MHz antenna. The ice (where thick and safe) provides a stable platform to conduct GPR surveys. Safety procedures were enforced throughout these surveys. If available, a snow-mobile or ATV would have sped the collection of data and allowed larger areas to be surveyed in the same amount of time.

As previously discussed, a Trimble AgGPS114 L-band DGPS antenna was used to georeference the radar data. In addition, Jim Turenne recorded coordinates of selected points along each traverse line with a Garmin Global Positioning System Map 76 receiver (Olathe, KS).[2] The selected points were for core observations made on previous surveys of these water bodies. Unfortunately, these points did not necessarily correspond with changes in GPR facies and most core data were unavailable for the preparation of this report. Limited ground-truth observations were made by Donald Parizek to help confirm interpretations and scale the radar imagery.

Calibration:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, bedrock) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to the reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (v) are described in the following equation (Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation:

$$E_r = (C/ v)^2 \qquad [2]$$

where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is commonly expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

The radar records were depth scaled based on the depths to the water/subaqueous soil interfaces at eight calibration sites located in the fresh water bodies that were surveyed. At these calibration sites, ice thickness varied from about 15 to 35 cm and depths to the water/subaqueous soil interface varied from 0.66 to 5.33 m. With the 70 MHz antenna, the estimated average E_r though columns of ice and water was 75.7, but ranged from about 39.9 to 89.2 at the eight calibration sites. The value 39.9 is incorrect. This error reflects faulty measurements or interface picking. The range in E_r was also affected by the relative thickness of the ice and water columns, and antenna frequency. Using the estimate of E_r, the average difference between measured (66 to 533 cm) and interpreted (65 and 543 cm) depths to the water/subaqueous soil interface at the eight calibration sites was only 13 cm, with a range of 7 to 38 cm.

Study Sites:
The surveyed ponds and reservoirs represent typical freshwater aquatic systems in the glaciated northeastern USA. Two of the sites are natural ponds and two are reservoirs, which were created as result

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of stream damming. The natural ponds are Tucker Pond (101 acres; 41.4225° N, 71.6356° W), and Worden's Pond (1043 acres; 41.4368° N, 71.5751° W). The impounded water bodies are Smith and Sayles Reservoir (176 acres; 41.8957° N, 71.6754° W) and Bowdish Reservoir (226 acres; 41.9221° N, 71.776° W) At the Smith and Sayles, and Bowdish Reservoirs, dams had been constructed to impound the water in 1865 and 1850, respectively. The ice thickness was to thin at Worden's Pond to permit GPR surveys. As a result, no data from this freshwater body will be reported.

Results:

Interpretations:

On all radar records shown in this report, high amplitude reflections are shown in shades of white, pink, and blue; intermediate reflections are shown in shades of yellow and green; and low amplitude reflections are shown in shades of red and black. On all records, the horizontal and vertical scales are expressed in meters. For display purposes, the vertical scales have been exaggerated.

Figure 2 is a representative radar record from Tucker pond. On this radar record, the interface separating water from bottom materials is clear and easily traced at depths ranging from 2.7 to 4.4 m.

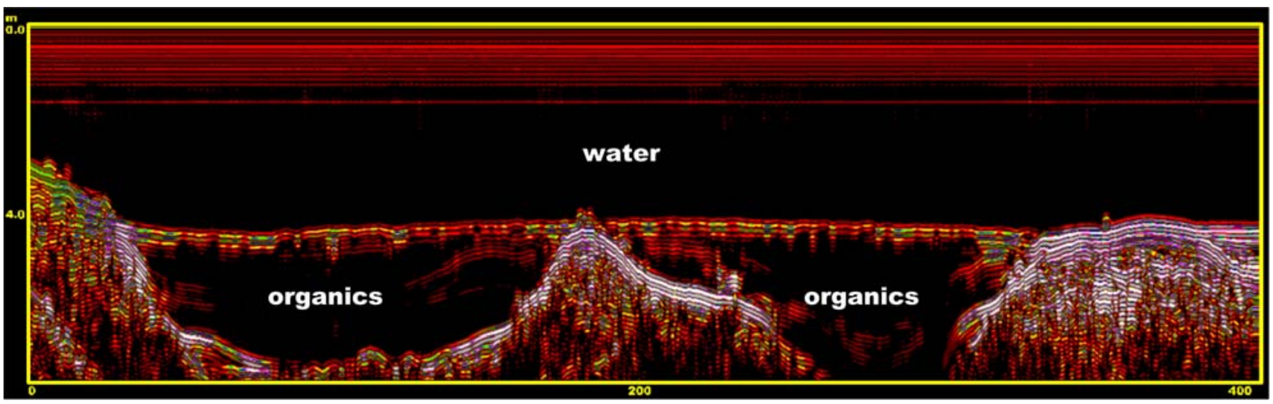

Figure 2. On this radar record from Tucker Pond, the interface separating water from subbottom materials is clear and easily traced. Bottom sediment type (mineral or organic soil materials), as well as bottom topography are also identifiable.

In Figure 2, major bottom sediment types (mineral or organic soil materials) can be distinguished base on the relative amplitudes and spatial patterns of the reflected signals. The greater and more abrupt the contrast in the relative dielectric permittivity (E_r) of two adjoining materials, the greater the amount of energy that will be reflected back to the antenna, and the greater the amplitude of the reflected signal appearing on radar records. Interfaces that have similar E_r are poor reflectors of electromagnetic energy and produce low amplitude reflections that are often difficult to detect on radar records. The *reflection coefficient*, *R*, is a measure of the strength (high to low amplitudes) of reflections and is expressed as (after Neal, 2004):

$$R = \frac{\sqrt{E_r 2} - \sqrt{E_r 1}}{\sqrt{E_r 2} + \sqrt{E_r 1}} \qquad [3]$$

where E_r1 and E_r2 are the relative permittivity of adjoining materials 1 and 2. As evident in equation [3], *R* is dependent on the difference in the E_r that exists between two adjoining materials.

Water has the highest E_r (80 to 81); air has the lowest E_r (1). The E_r of most dry and wet earthen materials ranges from about 3 to 8 and 10 to 30, respectively. The E_r of soil materials is strongly dependent upon moisture content. As a consequence, the *reflection coefficient* is greatly influenced by the abruptness and difference in moisture contents that exist between soil horizons, layers or features. Organic deposits often display considerable anisotropy in composition, moisture content and bulk density (Warner et al., 1990). In saturated organic soil materials, the reported E_r range from about 48 to 81. Differences in moisture contents have allowed some to distinguish organic layers that differ in degree of humification, bulk density, and dielectric permittivity.

On the radar record shown in Figure 2, the area of submerged organic soil materials (Wassists) are distinguishable by the low-amplitude reflections from the water/bottom materials interface and the absence of high amplitudes within the organic materials. Interfaces separating organic and mineral soil materials are typically expressed by high amplitude reflections, which reflect large differences in the moisture contents of these materials. In Figure 2, areas of mineral bottom materials (Wassents) are distinguished by high- and intermediate-amplitude reflections and the presence of reflections patterns, which suggests sequences layering or dissimilar mineral fabrics.

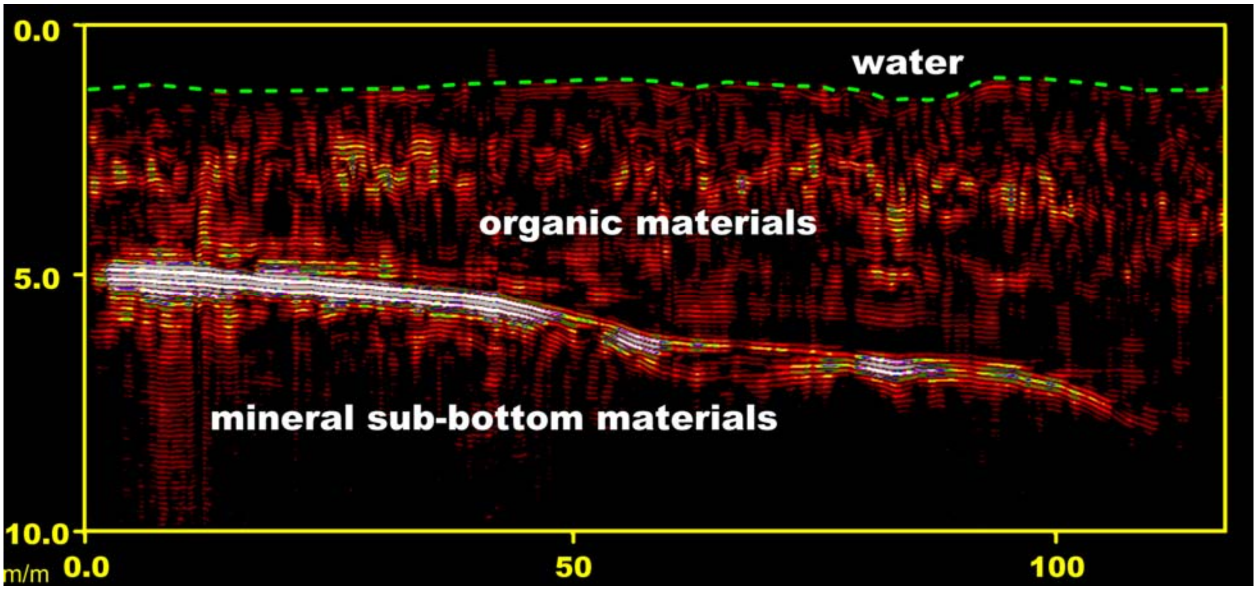

Figure 3. On this radar record from Bowdish Reservoir, the interface separating the water from the bottom organic materials is identified by its low amplitude and slightly wavy topography. Intermediate amplitude reflections within the organic are presumed to represent larger tree limbs and stumps.

The radar record shown in Figure 3 was obtained on Bowdish Reservoir. The interface separating the water from the submerged organic deposits is identified by its low amplitude, intermittent reflection patterns, and slightly wavy topography. A green-colored, segmented line has been used to highlight this interface on the radar record shown in Figure 3. Within organic materials, low amplitude reflections are believed to represent differences in the composition, moisture content, and bulk density. In the upper part of the submerged organic deposit shown in Figure 3, these features do not appear to be continuous, but seem scattered into irregular packets of mostly planar reflections. A zone or facies of intermediate amplitude reflections forms a prominent zone that stretches across the radar record between depths of about 2 to 3.7 m. These features are presumed to represent larger, buried tree limbs and stumps. Below 2.7 m and above the organic/mineral contact, is a GPR facies that appears to be composed of planar and more continuous reflectors. This subsurface facies suggest a more orderly, layered sequence of organic materials that are possibly intermixed with mineral soil layers, which create some intermediate amplitude reflections. These deposits reflect the varied history of this presently submerged environment.

Figure 4 contains a radar record that was collected on the Smith and Sayles Reservoir. The contact between the water and the underlying mineral soil materials has been highlighted with a green-colored, segmented line. Above a depth of about 3.5 meters, the mineral soil materials are layered and display low, but varied signal amplitudes. In areas where the amplitudes are very low (shades of darker red and black), the layers are presumed to be composed of more homogeneous, less contrasting materials. Between the 125 and 200 meter distance marks, a zone of higher-amplitude, planar reflections is evident within the zone of lower signal amplitudes. This feature is believed to represent contrasting channel-filled deposits. Below depths of about 3.5 meter, reflection patterns are more segmented and chaotically arranged suggesting till.

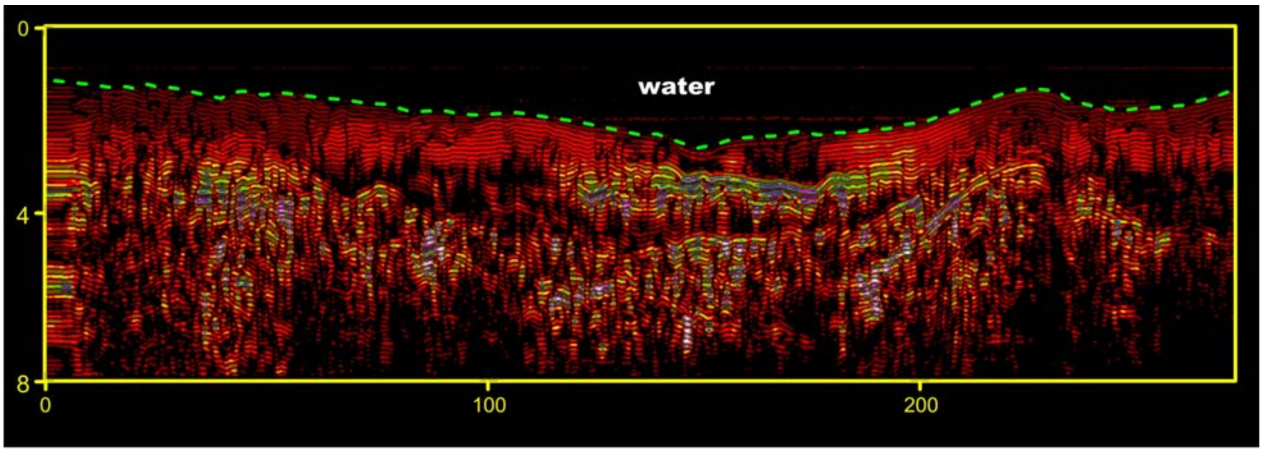

Figure 4. On this radar record from the Smith and Sayles Reservoir the contact between the water and the underlying mineral soil materials has been highlighted with a green-colored, segmented line.

The subaqueous soil environments that were surveyed as part of this investigation are exceedingly complex in terms of soil materials, topography and formative processes. This variability can be great over surprisingly short distances as testified in the radar records provided in this report. In order to accurately interpret the different radar reflection patterns and signal amplitudes, subaqueous soils should be cored for identification where patterns change. This was not adequately accomplished during this survey. As a consequence, subbottom materials were often difficult to properly identify. Timely and well-positioned cores will greatly improve GPR interpretations and should be carried out simultaneously with all future GPR surveys of freshwater subaqueous soils on ice.

<u>Bathymetry:</u>
The ice at Worden Pond was too thin to permit safe passage. Ground-penetrating radar surveys were conducted on Bowdish Reservoir, Smith and Sayles Reservoir, and Tucker Pond. All of these water bodies had sufficient ice thickness to be safe for pedestrian GPR surveys. These surveys were conducted to obtain data on water depths, nature of bottom sediments, subaqueous topography and areas suitable for the growth of invasive plant species.

A GPR bathymetric survey was conducted across the western portion of Bowdish Reservoir. Bowdish Reservoir is a relatively shallow, impounded lake that is underlain by relatively thick deposits of peat. The reservoir occupies a large, ponded peatland. Based on nine GPR traverses and over 36,600 GPR measurements, the average water depth was 1.42 m with a range of 0 to 2.61 m. At the time of this survey, one half of the water depth measurements were between 112 and 135 cm. The GPR survey revealed that the western portion of Bowdish reservoir is extremely shallow. Most areas within this portion of the reservoir are well within the proposed water depth limit for subaqueous soils (250 cm). Figure 5 is a Google Earth image of the reservoir showing the locations of the GPR traverses and water depths based on 1 m depth intervals.

Smith and Sayles Reservoir is a relatively shallow pond that is underlain by mostly mineral soil materials. Based on eleven GPR traverses and over 82,900 GPR measurements, the average water depth was 1.77 m with an observed range of 0 to 2.76 m. At the time of this survey, one half of the water depth measurements were between 153 and 199 cm. The GPR survey revealed that the Smith and Sayles Reservoir also contains relatively shallow waters. Most areas within this portion of the reservoir are well within the proposed water depth limit for subaqueous soils (250 cm). Figure 6 is a Google Earth image of the reservoir showing the locations of the GPR traverse lines on Smith and Sayles Reservoir and water depths based on 1 m depth intervals.

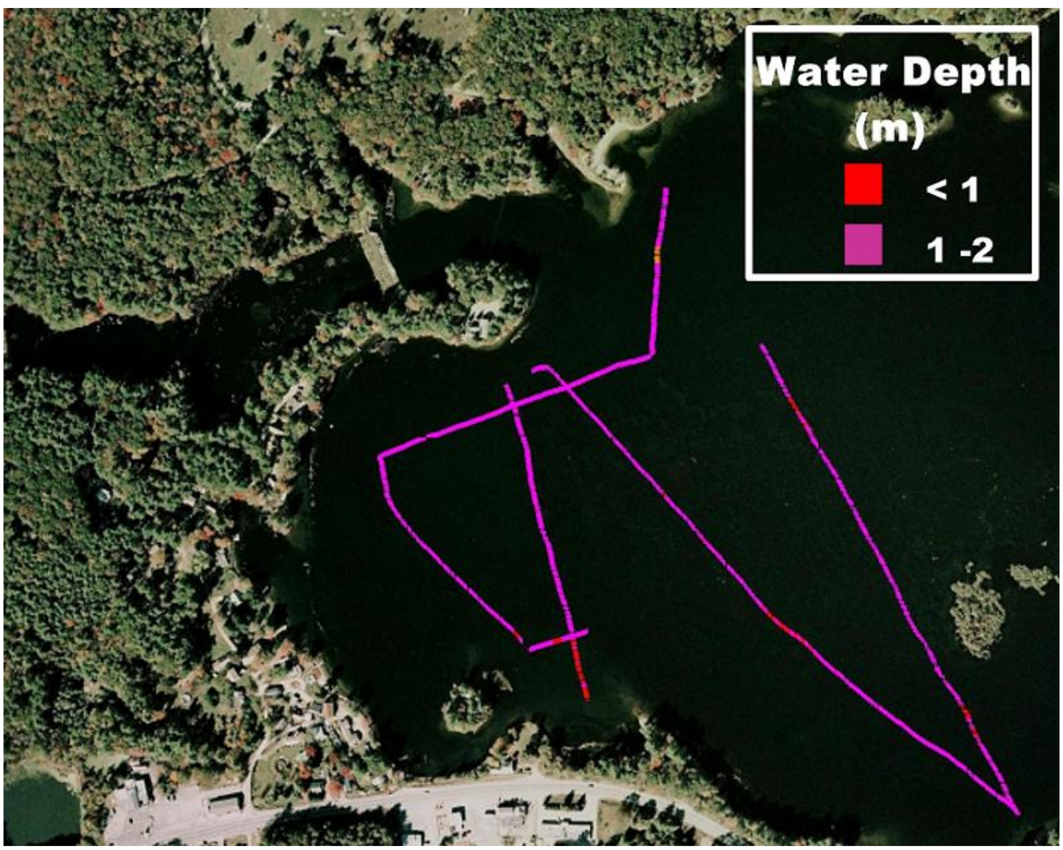

Figure 5. The depth of water in the western portion of Bowdish Reservoir. Depth classes are expressed in meters.

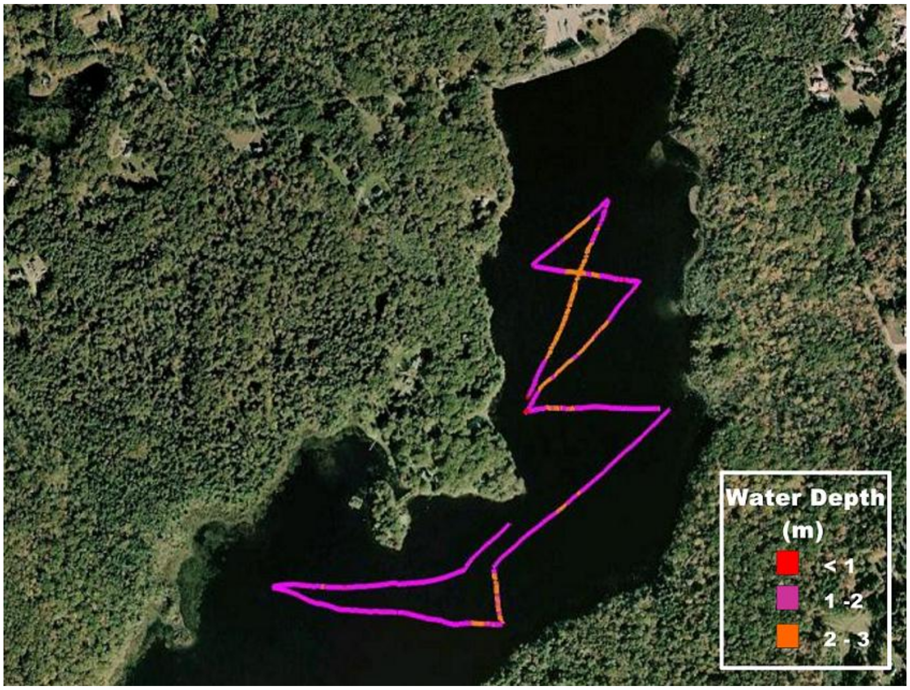

Figure 6. The depth of water in the northern portion of Bowdish Smith and Sayles Reservoir. Depth classes are expressed in meters.

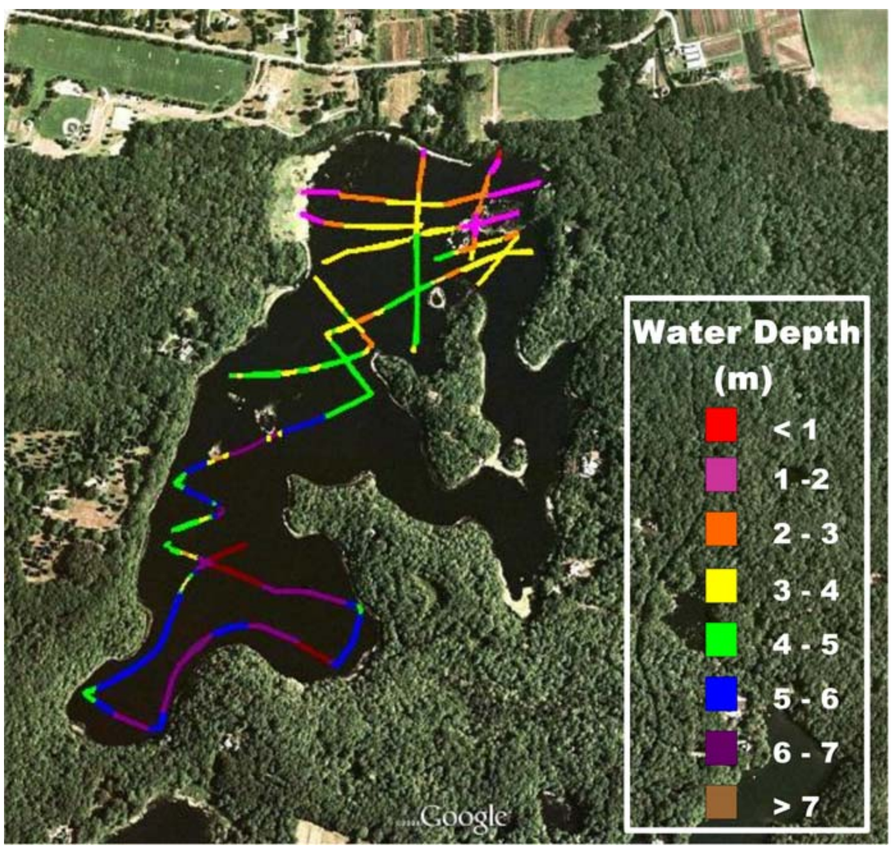

Figure 7. The depth of water in Tucker Pond. Depth classes are expressed in meters.

Tucker Pond is a relatively deep lake that is underlain by mineral soil materials. Based on twenty-one GPR traverses and over 149,400 GPR measurements, the average water depth was 4.54 m with an observed range of 0 to 7.68 m. At the time of this survey, one half of the water depth measurements were between 3.30 and 5.91 cm. The GPR survey revealed that Tucker Pond deepens towards the south and that most areas contain water columns that are greater than the proposed water depth limit for subaqueous soils. Figure 7 is a Google Earth image of the reservoir showing the locations of the GPR traverse lines on Smith and Sayles Reservoir and water depths based on 1 m depth intervals.

Poquonock Soils on Conanicut Island:

The soil staff in Rhode Island is updating its soils maps and desires to know if areas mapped as very deep Poquonock soils on Conanicut Island have inclusions of shallower to ledge soils. The study site (41.54253 ° N., 71.37329 ° W) is located in a hay land (Fig. 8). Delineations of Birchwood sandy loam (Bc), and Poquonock fine sandy loam on 0 to 3 (PsA) and 3 to 8 (PsB) % slopes were mapped in this field The very deep, well drained Poquonock and moderately well drained Birchwood soils form in moderately deep sand mantles overlying loamy till on uplands. Poquonock is a member of the mixed, mesic Typic Udipsamments family. Birchwood is a member of the mixed, mesic Aquic Udipsamments family.

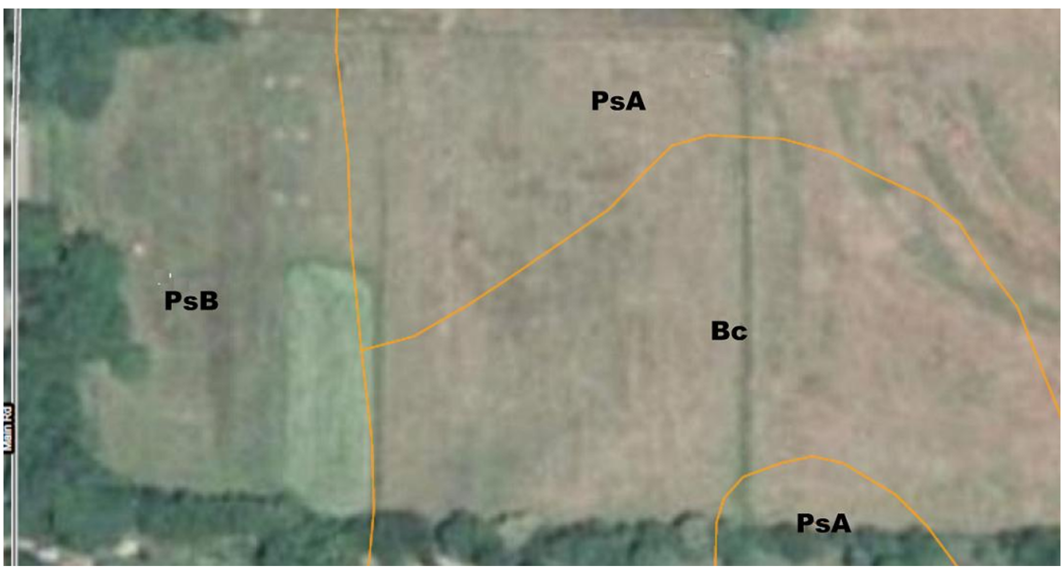

Figure 8. The soil map for the Poquonock soils study site on Conanicut Island.

Figure 9 is a representative radar record from the Poquonock site. All scales are expressed in meters. A white-colored, segmented line has been used to highlight the interpreted depth to a major subsurface interface. Above this interface and other than the surface pulses, the radar record is relatively free of reflections suggesting relatively homogenous materials. These homogenous materials represent the sand mantle. Below the homogenous sand mantle, reflection become more expressed and numerous suggesting highly contrasting materials. Though partially masked and difficult to perceive, there is an orderly, inclined, linearity expressed in the underlying materials. Green-colored, segmented lines have been used in Figure 9 to highlight some of these lineations. The orderly alignment and inclination of reflectors in the lower part of the radar record suggests bedding or cleavage planes of bedrock rather than the presence of till. If the underlying materials were till, reflection patterns would be more chaotic and lack inclined features (however, water reworked till cannot be ruled out nor can push features associated with glaciations). The closest point to which these incline reflectors approach the soil surface is interpreted as the soil/bedrock contact. The underlying parent rock is not homogenous, but has impurities and structural convolutions, which partially masks the inclination of the suspected cleavage planes. Under these interpretations, till is either lacking or represents a very thin deposit sandwiched between the sand mantle and the underlying parent rock.

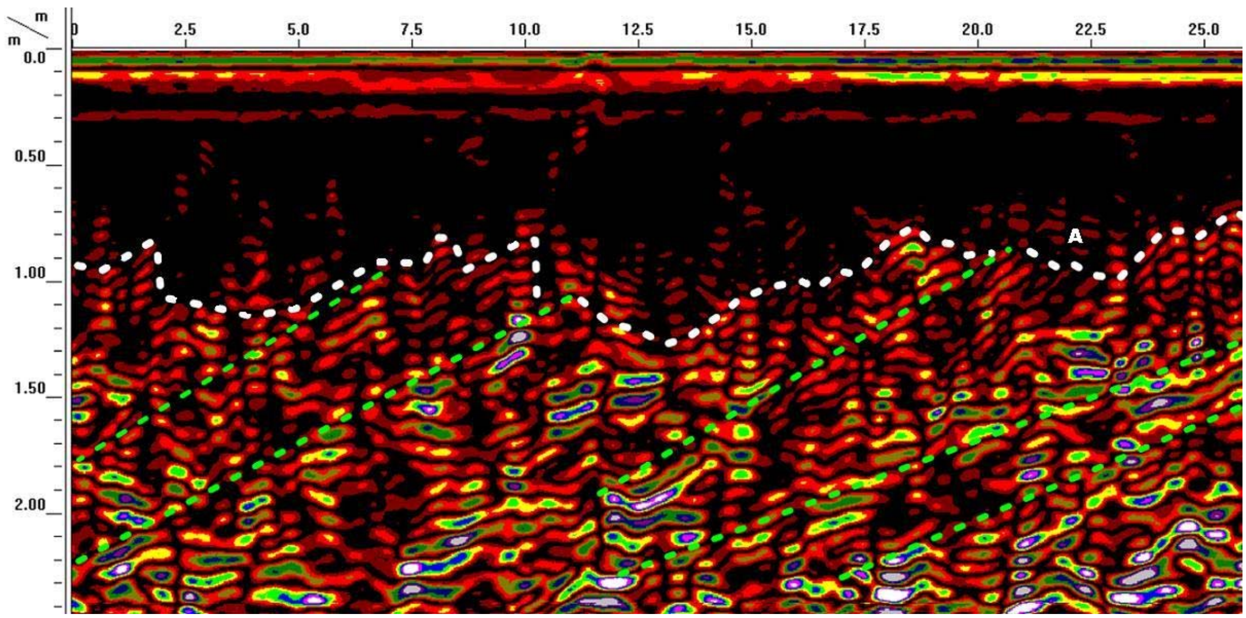

Figure 9. This radar record was collected in areas of Poquonock soils with a 200 MHz antenna. Segmented white and green-colored lines identify the interpreted soil/bedrock interface and cleavage planes in the underlying bedrock, respectively.

Two radar traverses (245 and 265 m long) were completed with the 200 MHz across the study site. Because of arrival of heavy snows and blizzard conditions, field work had to be abbreviated and an acceptable velocity of propagation was not obtained while in the field. Based on hyperbola matching techniques used during signal processing, an E_r of 11 and a *v* of 0.0895 m/ns were used to scale the radar records. Based on over 34, 800 picks on the two radar record using RADAN for Windows *interactive module*, soils within the study site were found to be dominantly deep (53%) and moderately deep (36 %) to bedrock. Only 11 % of the soils are very deep, the depth class for the mapped Birchwood and Poquonock soils.

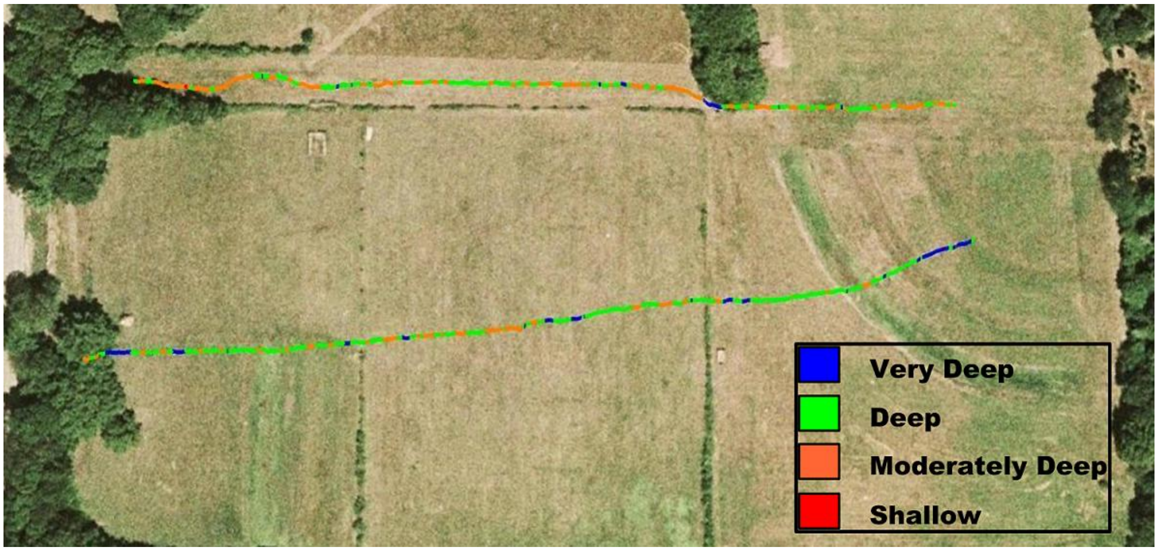

Figure 10. This Google Earth image shows the locations of the two GPR traverses that were conducted across the Poquonock site on Conanicut Island and the soil depth classes for bedrock depths that were picked from the GPR records.

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